Antenna Support Structure Aperture Blockage Loss

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Loss in antenna gain caused by support structure aperture blockage is probably the most difficult loss factor to measure or calculate. In this article the loss is determined experimentally for aluminum and fiberglass structural configurations, and empirical formulas are developed to calculate the loss for other similar configurations. Experimental and analytical data on the X-band RF transmission characteristics of thin fiberglass sheets are presented. It is concluded that fiberglass structures are far superior for minimizing gain loss.

Introduction

The feed or subreflector of an antenna must be attached to the reflector, and typically the required support structure blocks some of the RF energy, causing a loss in antenna gain. This effect is called blockage loss and has been considered by several authors (e.g., References 1, 2, and 3). The direct experimental determination of this loss is very difficult since it is necessary to (1) determine the total efficiency loss of the antenna by an absolute gain measurement, and (2) evaluate all loss factors other than the blockage loss. Both of these steps are difficult and typically introduce tolerances comparable to or larger than the effect being measured. Accurately calculating the loss for a conventional truss structure is even more difficult.

In this article, the loss is experimentally determined by comparing the gain of the antenna using a given configuration with the gain of the antenna using a configuration for which it is possible to accurately determine the loss *a priori*. The results are then used to develop empirical formulas for loss calculations, and to demonstrate that two types of fiberglass structures are far superior to aluminum structures for minimizing gain loss.

Support Configurations and Analysis

Two basic types of configurations were considered: a conventional strut-type structure as shown in Figure 1, and a single large cylindrical shell as shown in Figure 2. The structural members used in the first configuration consisted of fiberglass or aluminum tubes of different diameters; the second configuration used only one cylinder made of 0.38-mm (0.015 in.)[1]-thick fiberglass.

The analysis of the second structure, shown schematically in Figure 3, is relatively simple. For low transmission loss, multiple reflections within the cylinder may be neglected; also the radius of curvature is large compared to a wavelength, so the net loss is closely approximated by the loss of a plane wave incident on an infinite fiberglass sheet of the same thickness.

To determine the dielectric properties of the fiberglass at the 8448-MHz test frequency, several samples were tested using a method reported previously (Reference 4) in which the test sample is inserted across a section of WR 112 waveguide. As described in the above reference, at 8448 MHz this is equivalent to having a plane wave incident at 0.672 rad (38.5 deg) from the normal to the surface, with the E-field normal to the plane of incidence. The test results for three thicknesses are shown in Figure 4. Also shown are calculated results for three values of the dielectric constant ϵ, which were obtained from a computer program developed by Otoshi.[2] It is seen that for a dielectric constant of 5.0, the computed data matches the measured data reasonably well. This value of the dielectric constant is in the correct range for fiberglass (Reference 5). Using this value, the loss of a fiberglass sheet may be calculated for various angles of incidence as given in Figure 5.

To confirm this data, the transmission loss was directly measured by inserting a fiberglass sheet between two horn antennas. Compared to the waveguide measurement, this technique has the advantage of allowing measurement of either polarization for any angle of incidence, but has the disadvantage of diffraction effects which can be difficult to estimate. However, the measured data agrees very well with the computed data as shown in Figure 5, resulting in high confidence in the data.

For the support configuration shown in Figures 2 and 3, the angle of incidence γ is 0.524 rad (30 deg). For either the case of linear or circular polarization (due to the circular symmetry of the structure), the loss will

[1]Where applicable, the International System of Units is stated first, followed by the customary units in parentheses. In each case, the value in parentheses represents the measured or calculated unit.

[2]Otoshi, T. Y., private communication.

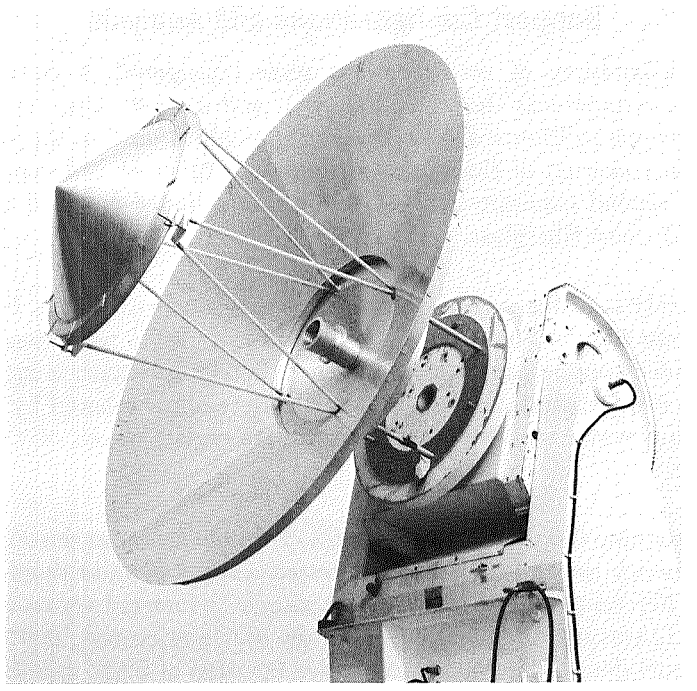

Figure 1. Strut support structure

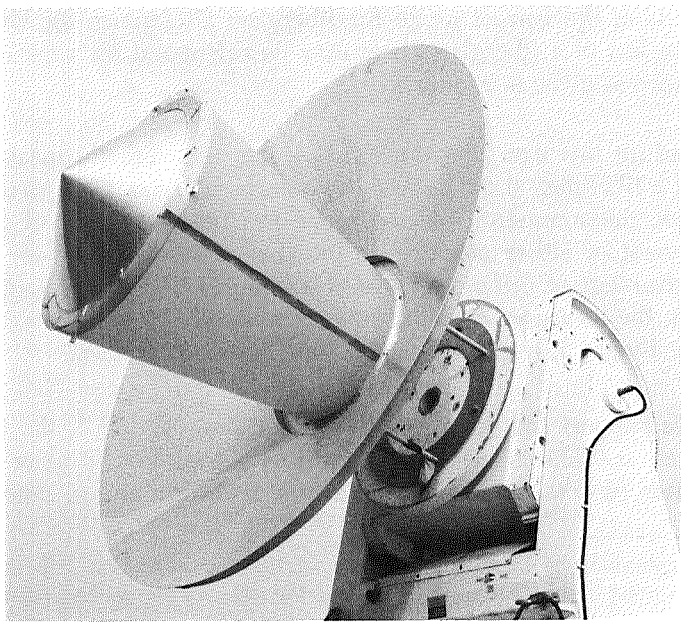

Figure 2. Cylindrical shell support structure

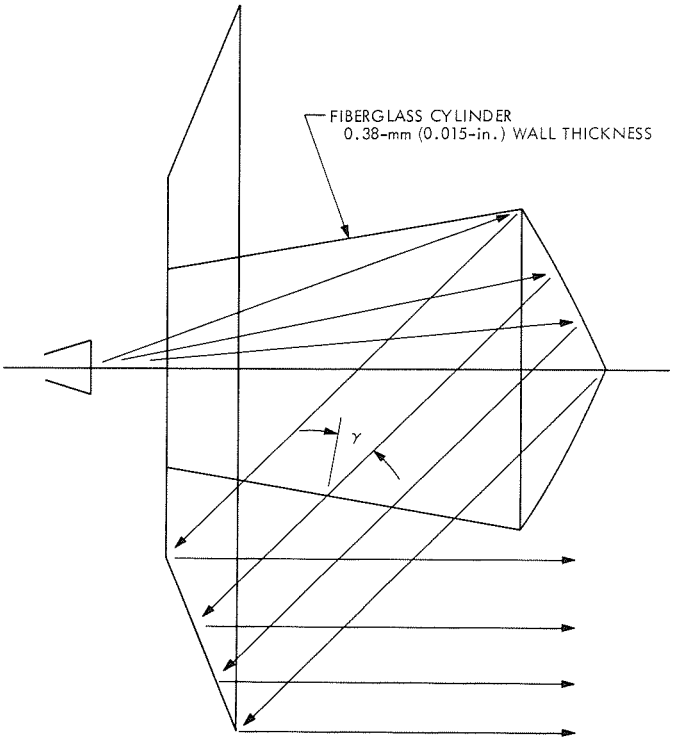

Figure 3. Cylindrical support structure for conical antenna subreflector

be the rms average of the values for E-field normal, and E-field perpendicular to the plane of incidence. Using the information in Figure 5, the loss is calculated to be 0.08 dB. There is an additional 0.05 dB of loss due to three joints where the thickness is doubled. The net loss of the structure in Figure 2 is therefore 0.13 dB. A conservative estimate of the tolerance on this value is ±0.08 dB.

The analysis of the strut structure shown in Figure 1 is not as straightforward or nearly as accurate as the cylinder analysis. In general, loss due to aperture blockage arises from two factors: (1) a fraction of the aperture is shadowed, reducing the effective aperture area of the antenna; and (2) a fraction of the radiated power is lost. To a first approximation, these two effects are equal and if the fractional area blocked is ΔA, the blockage efficiency is given approximately by

$$\eta_B = (1 - \Delta A)^2 \tag{1}$$

Somewhat more sophisticated results are given in the References 1, 2, and 3, but the whole approach is based on such uncertain assumptions that it is not clear that anything more complicated than Equation 1 is justified. (The main questionable feature is that, typically, the structural members have dimensions on the order of a wavelength, but diffraction

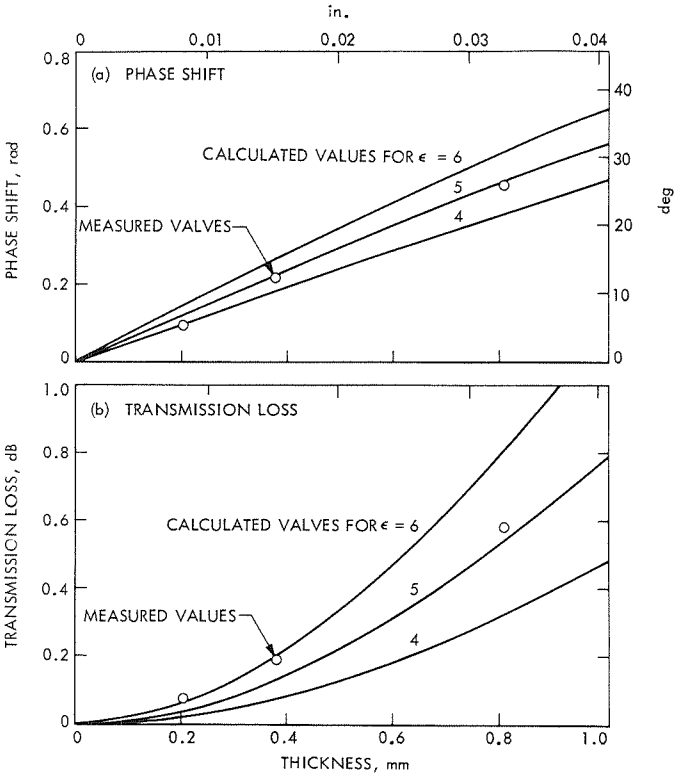

Figure 4. RF effect of fiberglass sheet in WR 112 waveguide at 8448 MHz

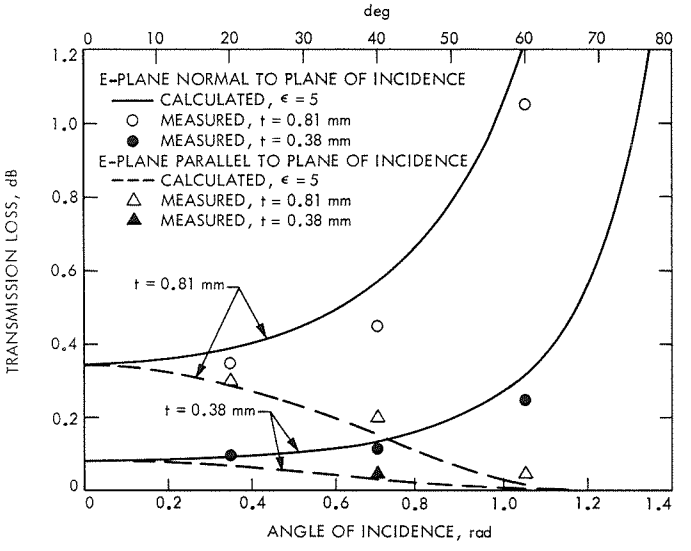
deg
E-PLANE NORMAL TO PLANE OF INCIDENCE
CALCULATED, ϵ = 5
MEASURED, t = 0.81 mm
MEASURED, t = 0.38 mm
E-PLANE PARALLEL TO PLANE OF INCIDENCE
CALCULATED, ϵ = 5
MEASURED, t = 0.81 mm
MEASURED, t = 0.38 mm
t = 0.81 mm
t = 0.38 mm
TRANSMISSION LOSS, dB
ANGLE OF INCIDENCE, rad

Figure 5. Transmission loss vs angle of incidence for fiberglass sheets of two thicknesses

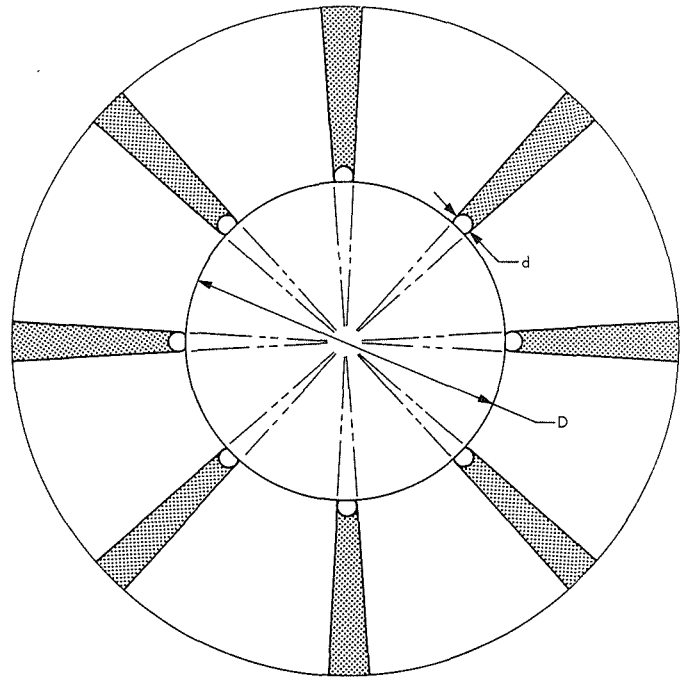

Figure 6. Area shadowed by strut structure

effects are not considered.) One modification of this application to Equation 1 has been suggested (Reference 6) which does appear to be useful; the blocking structure is assumed to be partially transparent with an opacity coefficient α, and an effective blocked area is defined by

$$\Delta A_{eff} = \alpha \Delta A \tag{2}$$

so the loss is given by

$$\eta_B = (1 - \alpha \Delta A)^2 \tag{3}$$

For a perfect conductor, neglecting diffraction effects, one would expect the opacity factor to be 1.0. For a fiberglass tube, the opacity may be estimated by averaging the transmission loss and loss due to phase shifts over various angles of incidence. Based on this very rough approach, for a 0.51-mm (0.020-in.) wall tube with a wave incident at 0.524 rad (30 deg), one would expect an opacity of about 30%, and for a 0.89-mm (0.035-in.) wall, an opacity of about 65%. However, the tolerance on these estimates is near a factor of 2.

The blocked area ΔA is defined as the projection of the optical shadow of the support members on the aperture area of the antenna. Referring to Figure 6, which is a head-on view of the antenna, if the struts of

diameter d were all parallel to the axis of the antenna, and were located on a circle of diameter D, then we would have

$$\Delta A = \frac{\pi D - 8d}{\pi D} \tag{4}$$

In the actual test antenna configuration shown in Figure 1, the struts are not parallel to the axis, but Equation 4 is still a good approximation for the area.

Experimental Results

The various structures were used to support the subreflector of the conical antenna as shown in Figures 1 and 2. The relative gain of the antenna with the various structures was then measured using a bolometer detector and HP 415 meter (1800-Hz signal modulation). Since the support structure loss is known for the case of the cylinder, this was used as the normalization to determine the absolute loss of the other structures.

Using this normalization, where the loss of the cylinder is taken to be -0.13 dB, the values shown in Table 1 are obtained. The indicated tolerance of ± 0.10 dB includes measurement errors as well as the tolerance on the calculated cylinder loss. Also shown in Table 1 are the blocked areas for the various cases. Using values for the blocked area and the loss, Equation 3 may be used to empirically determine the effective blocked area and values of α, which are also shown in Table 1. It is seen that for aluminum tubes of this size the effective area is substantially larger than the actual area, resulting in an opacity greater than the expected value of 1.0, whereas the effective area of the thin fiberglass tubes is much less than the actual area, and the opacity is less than the expected value. Of course, in both cases, the expected opacity

Table 1. Measured blockage loss and empirical values of effective opacity

Case	Aluminum struts		Fiberglass struts	
	1.27-cm diam	3.81-cm diam	1.27-cm-diam, 0.09-mm-thick wall	5.72-cm diam, 0.51-mm-thick wall
Measured blockage loss, dB	0.52 ± 0.10	2.03 ± 0.10	0.10 ± 0.10	0.29 ± 0.10
Fractional blocked area, %	3.9	11.6	3.9	17.4
Effective blocked area, %	5.8 ± 1.0	20.8 ± 0.9	1.1 ± 1.1	3.3 ± 1.1
Opacity α	1.5 ± 0.3	1.8 ± 0.1	0.3 ± 0.3	0.19 ± 0.06

Table 2. Calculated blockage loss for TOPS high-gain antenna

Case	Aluminum strut (3.81-cm diam)	Fiberglass strut (5.72-cm-diam, 0.51-mm wall)	Fiberglass cylinder (0.38-mm wall)
Fractional blocked area, %	8.7	12.0	100
Opacity α	1.8	0.19	0.016
Effective blocked area, %	15.7	2.3	1.6
Expected blockage loss, dB	1.5	0.20	0.14

values were very rough estimates. Unfortunately, the estimated tolerance swamps out the value of α for the case of the small fiberglass tube, but in the other cases the value is reasonably well determined. These empirical values of opacity may be used in Equation 3 to extrapolate the results to other antennas with similar configurations. For example, the loss of several proposed support structure configurations for the Thermoelectric Outer-Planet Spacecraft (TOPS) high-gain antenna are shown in Table 2.

To compute the loss of a cylindrical support for a conventional paraboloidal reflector is more difficult than the case of the conical reflector. For the conical antenna the angle of incidence is constant; for the TOPS paraboloidal reflector the angle of incidence varies as show in Figure 7. If we divide the antenna into several regions and take the angle of incidence as being constant within each region, approximate values of the voltage transmission coefficient t and relative phase shift $\Delta\phi$ may be obtained as given in Table 3. The relative phase shift is the difference

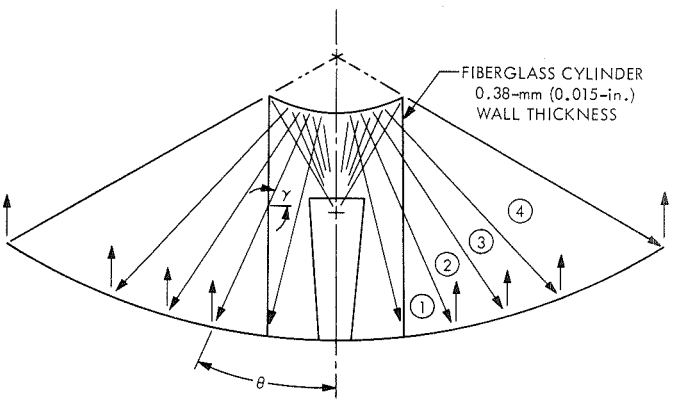

Figure 7. Cylindrical support structure for conventional paraboloidal antenna subreflector

Table 3. Transmission parameters for 0.38-mm (0.015-in.) fiberglass cylindrical support for paraboloidal antenna subreflector

Region	Range of ray angle θ, deg	Approximate angle of incidence γ, deg	E-field normal to plane of incidence			E-field parallel to plane of incidence			Fractional aperture area ΔA
			$t_\perp$	$\Delta\phi_\perp$, deg	$\tau_\perp$	$t_\parallel$	$\Delta\phi_\parallel$, deg	$\tau_\parallel$	
1	15–25	70	0.929	−11.4	0.911	0.9995	3.4	0.998	0.0944
2	25–35	60	0.964	−5.6	0.959	0.9993	3.3	0.998	0.1492
3	35–45	50	0.978	−2.9	0.976	0.9977	2.6	0.997	0.2141
4	45–60	40	0.984	−1.5	0.984	0.9957	1.7	0.995	0.5423

between the actual phase shift through the sheet for a given region and the average phase shift of all regions. The effective voltage transmission coefficient τ is then given by $\tau = t \cos \Delta\phi$. The net transmission coefficient of the cone is then given by an area weighted rms average of the transmission coefficients

$$\tau_{\text{net}} = \sum_{\substack{\text{all} \\ \text{regions}}} \frac{1}{2} \left(\tau_{\parallel}^2 + \tau_{\perp}^2 \right) \Delta A \tag{5}$$

This yields a value of $\tau_{\text{net}} = 0.9841$ for the data of Table 3, which corresponds to the loss of 0.14 dB given for this case in Table 2.

These results demonstrate the clear RF superiority of fiberglass structures over the aluminum structures (all structures are mechanically nearly equivalent) for the TOPS antenna.

Conclusion

It has been experimentally determined that aluminum tubes 1–2 wavelengths in diameter have an effective blockage area approximately 1½–2 times their physical area and that thin wall fiberglass tubes have an effective blockage area much less than their physical area. Both thin wall fiberglass tubes and large fiberglass cylinders are very good support structures for reducing gain loss. It should be noted that dielectric structures have an adverse effect on the system temperature of very low noise receiving antennas, so although the fiberglass structures are very attractive for relatively noisy spacecraft antenna systems, they are not necessarily attractive for low noise ground antennas.

References

1. Gray, C. L., "Estimating the Effect of Feed Member Blocking on Antenna Gain and Sidelobe Level," *Microwave J.*, pp. 88–91, Mar. 1964.

2. Wested, J. H., "Shadow and Diffraction Effect of Spars in a Cassegrainian System," Report P2118. Microwave Laboratory, Danish Academy of Technical Sciences, Copenhagen, Denmark, Mar. 1966.

3. Ludwig, A., "Efficient Antenna Systems: Aperture Blockage and Surface Tolerance Loss Calculations for Non-Uniform Illumination and Error Distribution," in *The Deep Space Network*, Space Programs Summary 37-41, Vol. III, pp. 89–90. Jet Propulsion Laboratory, Pasadena, Calif., Sept. 30, 1966.

References (contd)

4. Woo, K., and Otoshi, T. Y., "Spacecraft Antenna Research: An RF Study of Reflector Surface Materials for Spacecraft Antennas," in *Supporting Research and Advanced Development*, Space Programs Summary 37-61, Vol. III, pp. 99–106. Jet Propulsion Laboratory, Pasadena, Calif., Feb. 28, 1970.

5. Handbook of Chemistry and Physics, 50th Edition, p. E-66. Edited by R. C. Weast. Chemical Rubber Co., Cleveland, Ohio, 1969–1970.

6. Potter, P. D., *The Design of a Very High Power, Very Low Noise Cassegrain Feed System for a Planetary Radar*, Technical Report 32-653. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 24, 1964.